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Radio Module Characteristics and Their Relevance to Fire Detection Systems

1. Introduction

Integrating wireless fire detectors into a fire detection system offers the user many advantages (see “Technical State of 868-870 MHz Radio Modules with SRD Band” in the same conference volume). Since this new technology must cover the same risks as conventional fire detection systems, the same requirements naturally apply to the quality of the radio link. With modern transmission processes and high-quality hardware, it has recently become possible to achieve the same quality as that of tried and trusted wired systems.

While the committed security expert is well able to discuss the advantages and disadvantages of any transmission process with the relevant supplier, the details which determine the hardware functionality of radio systems are almost certainly a mystery to him/her. This presentation attempts to shed some light on the most important technical terms and to explain their relevance to fire detection systems.

2. Propagation attenuation

One of the first questions always asked is “What is the range of your radio link in the building? ” In order to impress, various manufacturers therefore give the outdoor range. This value has very little meaning because there is no concrete reference basis. In a building, the waves are attenuated by more than a power of ten compared with unhindered propagation.

The attenuation of radio waves in a building depends entirely on the physical design properties and the distance between the transmitter and receiver. The manufacturer of a fire detection system cannot generally influence these matters and can only control the transmitted power and, above all, the sensitivity of the receiver. Instead of specifying distances, it would therefore be better to specify the attenuation budget, the attenuation reserve and the carrier frequency:

The attenuation budget is a measure of the range in the building.

2.1 Attenuation budget

The attenuation budget is the difference between the radiated transmitter power and the minimum received power required for good reception. The higher the value, the greater the range of the radio link, although it is important to remember that the attenuation in the masonry depends heavily on the frequency. A direct comparison can only be made between two values if the frequency is the same (see 2.3).

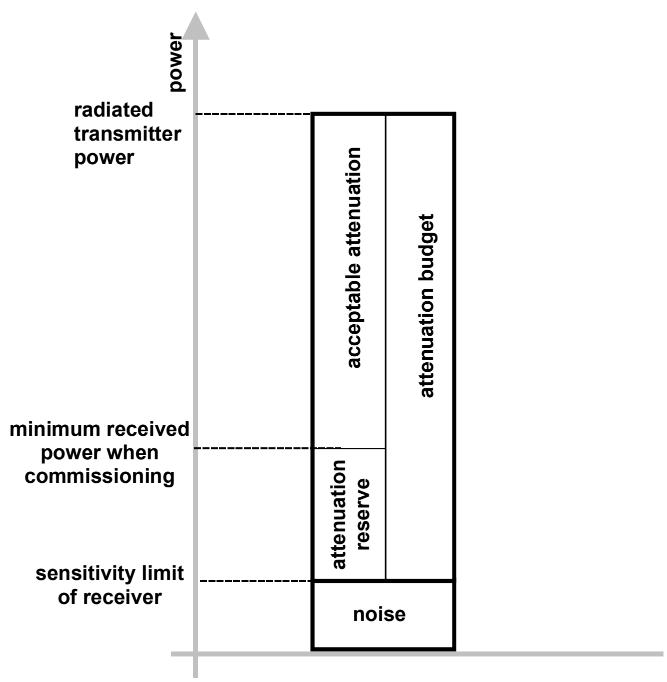


Figure 1 The attenuation budget

Some brochures highlight the transmitted power even though doubling it only means an increase of 3 dB in the attenuation budget while doubling the current drawn from the battery! Investing in receiver sensitivity makes greater sense (figure 1). For example, SIGMASPACE has an attenuation budget of approx. 115 dB.

20 dB more received sensitivity = 100 times greater transmitted power

2.2 Attenuation reserve

For various reasons which could have a negative (or positive) effect on wave reflection, e.g. moving cupboards or plant pots, or even wet window panes, the propagation conditions in a building are constantly changing, so that a path which has a barely adequate power level should not be commissioned. A comparatively large attenuation reserve is essential in order to ensure a reliable link for a period of several years. In the case of SIGMASPACE, an attenuation reserve of more than 25 dB was chosen. This produces an effective attenuation of approx. 90 dB.

Effective attenuation = attenuation budget – attenuation reserve

2.3 Frequency-dependant attenuation

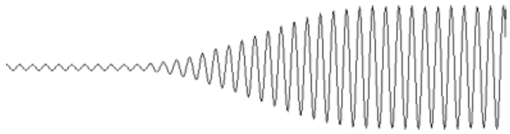
If waves penetrate dense materials such as wood, concrete or masonry, then both electrical and magnetic field components interact with their atoms and molecules so that there is a linear increase in attenuation which is roughly in line with the increase in frequency.

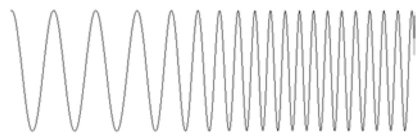
Generally speaking, the higher the frequency, the smaller the aerials. Smaller ones draw less energy from the electromagnetic field than large ones.

Rule of thumb: If the frequency is doubled, it is at the expense of approx. 10 dB of the received signal in buildings.

3. Types of modulation

In addition to conventional amplitude (AM) and phase or frequency modulation (FM) (figure 2), a buzz word frequently used these days is “spread spectrum modulation”. It is explained in greater detail in section 6.





Amplitude modulation Frequency modulation

Figure 2 Amplitude modulation und Frequency modulation

3.1 AM and FM

For noise and distortion-free demodulation,

- the overall amplification in AM receivers must be precisely regulated to the demodulator operating point and
- the mixing frequency in FM receivers must be tuned precisely to the received signal.

Since interference and changes in the transmission path affect the received amplitude but not the frequency, FM is thought to be more robust.

FM less sensitive to interference than AM

Note:
Narrow-band direct conversion receivers must also regulate their amplitude and can therefore respond to fluctuations in amplitude with distortion.

3.2 Spread spectrum modulation

Within the comparatively narrow bandwidths in the ISM band at 433 MHz and in the SRD band at 870 MHz which have been approved for Europe, there is probably little sense in using this wide band transmission method for fire detection systems.
For further information regarding spread spectrum see section 6.

> In Europe's narrow SRD band, spread spectrum modulation seems to make little sense for fire detection systems.

4. Transmitters

In all likelihood, a "bad" transmitter", i.e. one which produces several spurious emissions will not have a negative impact on its own transmission path. It is more likely to interfere with other services or even other transmission paths for the same fire detection system, so that it results in inefficient utilisation of the frequency spectrum which, by its nature, is limited.

5. Receivers

Receivers must filter out and amplify signals of the order of pW from the spectrum and in the process must not allow interference either from processes in neighbouring channels or electromagnetic influences. A truly enormous task. In order to tackle it, double detection receivers (heterodyne) are almost always used these days. Regenerative detectors are no longer in general use and ultra wide band receivers which use correlators, have barely gone beyond the development stage.

5.1 Heterodyne with one or more intermediate frequencies

Figure 3 shows the major function blocks of a heterodyne receiver with an intermediate frequency (IF). In principle, the variants with two intermediate frequencies (double super) do not offer any advantage or disadvantage, they are simply design variants. They tend to provide better image frequency suppression and filtering.

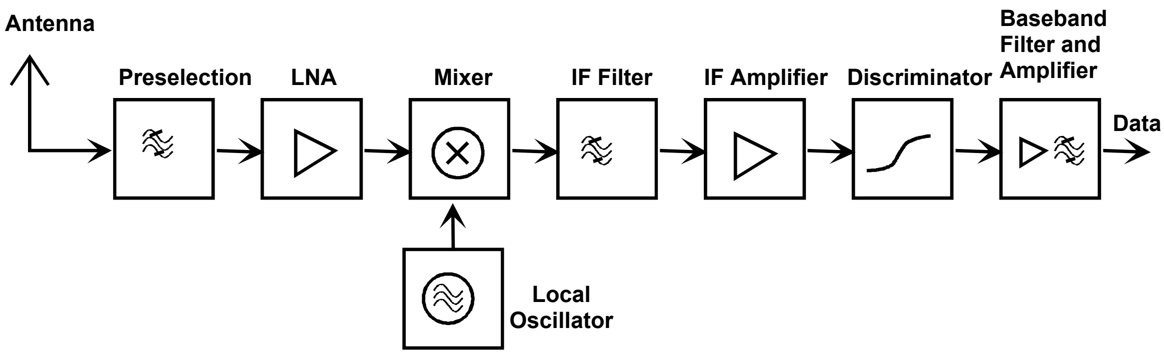


Figure 3 Circuit diagram of a heterodyne receiver

5.1.1 Preselection

In general, only high-quality radio modules have effective preselection which is fitted with effective components (e.g. surface wave resonators). While they attenuate the received signal by a few dB – which can be easily compensated by carrying out the next steps - they do improve:

- electromagnetic compatibility and therefore
- suppression of distant interference signals:

An oscillating antenna circuit consisting of inductances and capacitances is a rather poor compromise. Even with the antenna's selectivity, it only improves distance selection a little.

> Effective preselection improves EMC and suppresses the image frequency.

5.1.2 Preamplifier and mixer

Preamplifiers are mainly used in places where very low signals need to be received. In doing so, they must not be overloaded with large signals missed by the preselection operation.

Along with the mixer and IF filter function blocks which follow it, the preamplifier determines the receiver dynamic range, i.e. the ability to register a small wanted signal in addition to a strong signal in one of the neighbouring channels (figure 4).

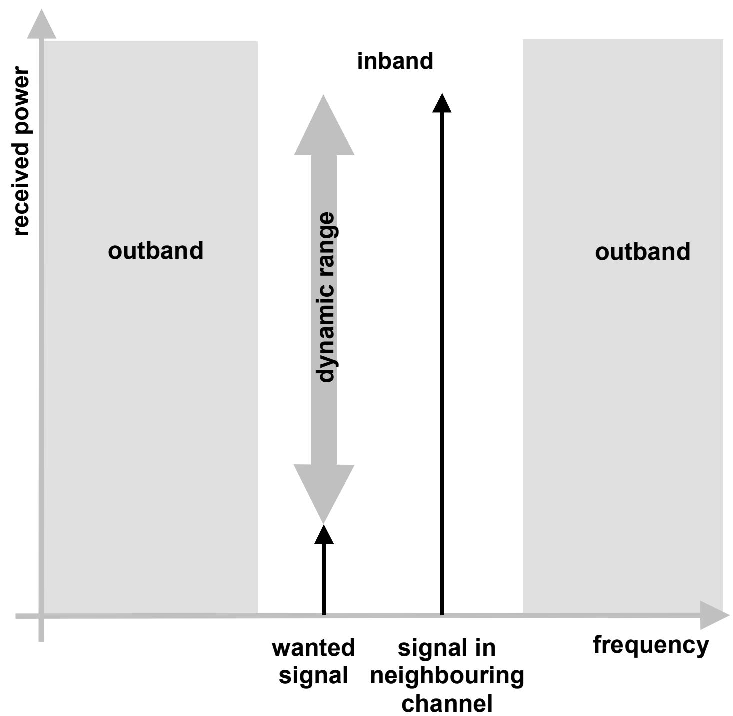


Figure 4 Dynamic range

In fire detection systems, the receiver dynamic range should be at least 60 dB.

Generally speaking, high-quality mixers and preamplifiers require comparatively high operating current. An acceptable level of energy consumption for the detector can only be guaranteed if the circuit concept is carefully chosen.

5.1.3 Local oscillator

The local oscillator must deliver a very clean signal, i.e. one which is free of spurious emissions or noise. For the mixer, every spurious emission, and even the oscillator signal noise, is seen as an additional mixer frequency, i.e. one with which it mixes unwanted signals from the spectrum into the IF (figure 5).

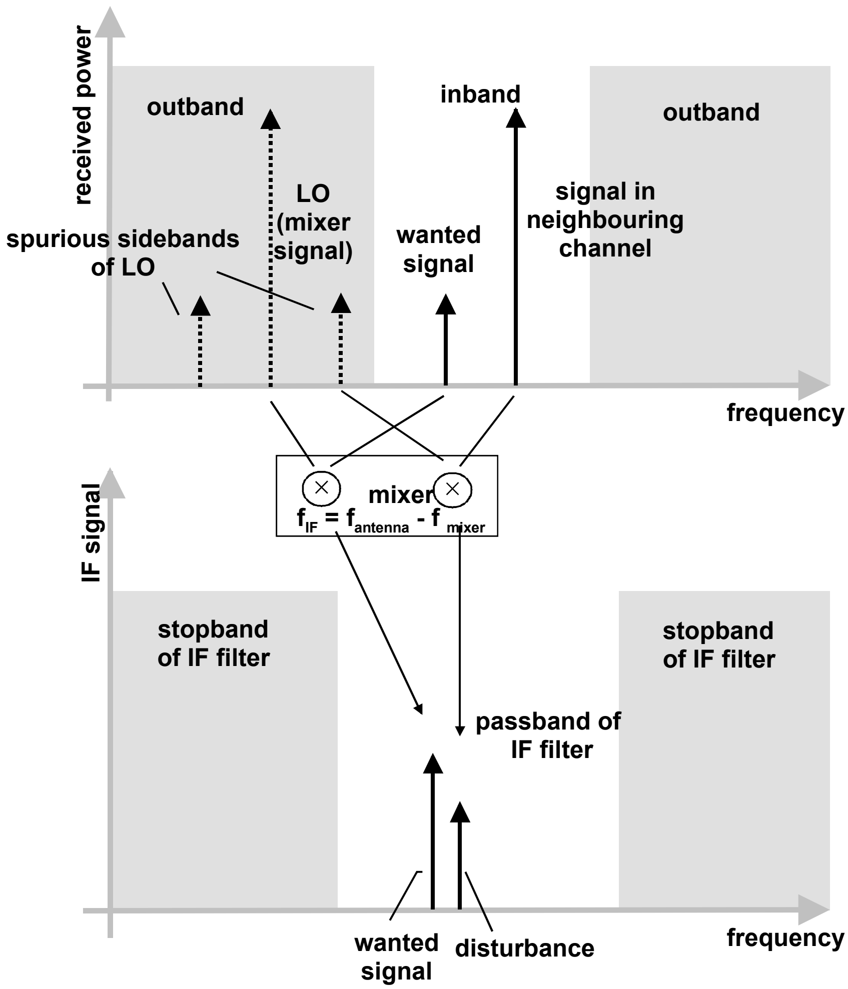


Figure 5 Unwanted mixed frequencies

Narrow-band receivers such as those required for the 25 kHz wide alarm channels in Europe's SRD band, demand very high quality in relation to the cleanness of the oscillator signal. This applies in particular to the immediate vicinity of the actual mixed frequency.

In high-quality receivers of approx. 900 MHz, the mixer frequency cannot be directly produced with the required precision in the local oscillator. A voltage controlled oscillator (VCO) supplies the output signal. It is linked to a lower oscillating quartz via a phase locked loop (PLL) (figure 6).

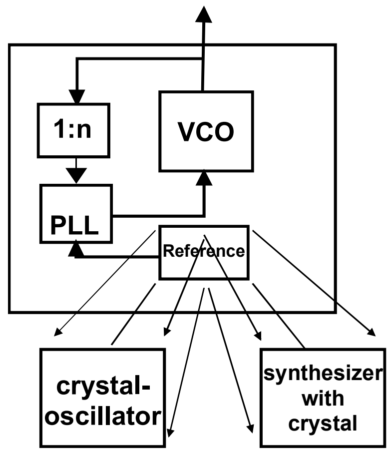


Figure 6 Basic structure of a local oscillator

Based on a single stable frequency, in transceivers, a synthesiser between the quartz oscillator and the PLL allows the creation of the transmission signal and the LO signal for the receiver mixer. For receivers which can operate in several channels, it supplies the variable reference frequency.

Unfortunately, synthesisers produce unavoidable spurious emissions. Precautions must therefore be taken to ensure that these do not couple to the mixer signal through the PLL. Otherwise other channels would mix and cause interference at the IF.

> LO noise and spurious emissions should be suppressed 10 dB more than the required receiver dynamic range.

5.1.4 The discriminator

At this point, the only type of demodulator worth considering is the discriminator because amplitude modulation is not used in high-quality fire detection systems.

In principle, the discriminator is a frequency-dependent resistor. It converts the IF frequency variation into a variation in amplitude (figure 7).

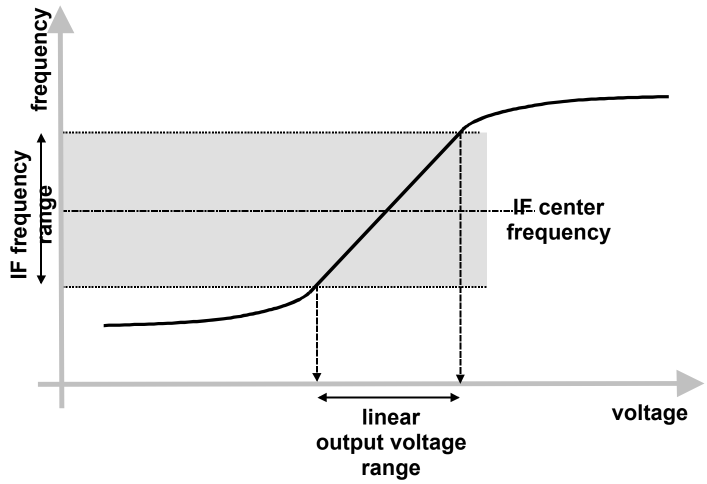


Figure 7 Discriminator curve

In order to achieve the greatest possible discriminator efficiency, the received signal must be mixed quite precisely at the middle of its linearity range. Broad-band receivers are somewhat less critical. Their quartz precision is generally sufficient to pinpoint the middle with sufficient accuracy. With narrow-band receivers, however, costly control mechanisms are required to tune the receiver to the transmitter.

Low priced broad-band solutions often also require frequency regulation because their reference oscillator is too imprecise. Simple versions of these regulation circuits are unable to transmit several “ones” or “zeros” in succession without becoming deregulated and verging on the limits of the discriminator’s linearity range. Direct current-free basic channel coding (Manchester code, return to zero code) solves the problem, although it takes up double the bandwidth. Owing to the greater noise levels in broad-band receivers, they are somewhat less sensitive.

> The maximum sensitivity and optimum utilisation of the spectrum can only be achieved with discriminators which can demodulate data which has a direct current component.

5.1.5 Base-band filter and base-band amplifiers

Owing to the current state of the art, base-band filters and amplifiers no longer have a negative effect on transmission quality, so there is no need for any further discussion.

5.2 Single chip double detection receivers

In conventional double detection receivers, IF filtering cannot yet be integrated on silicon. At present, active filters can only be used up to approx. 100 kHz. Recently, therefore, two different receiver principles which can be satisfactorily integrated have appeared on the market, or will do so in the near future:

- Receiver with low IF
- Direct conversion

5.2.1 Direct conversion

In receivers with direct conversion (DC – not to be confused with the abbreviation for direct current!), the IF is at 0 Hz. With conventional discriminators, the resultant signal cannot be demodulated because both positive and negative frequency deflection of an FM signal is reproduced as a positive frequency in the “IF” (figure 8).

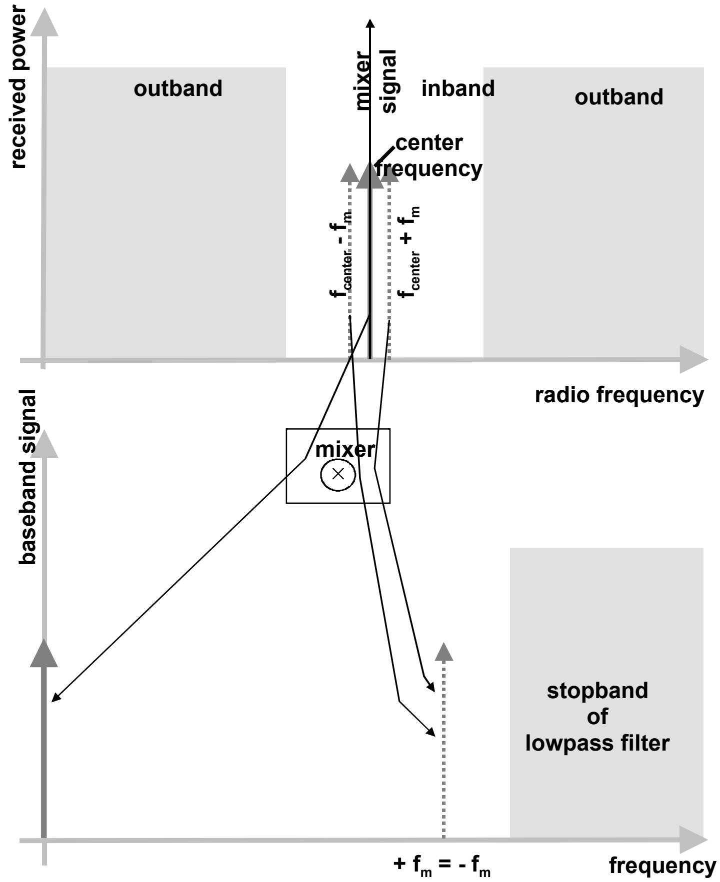


Figure 8 Mixing in direct conversion receivers

Figure 9 shows the amplitude-time curve of a 0/1 transition. The clearly recognisable irregularity originates from the phase change at the RF level.

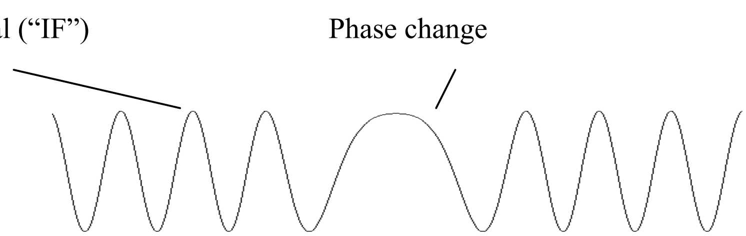


Figure 9 Amplitude-time diagram of a signal mixed at 0 Hz

However, demodulation is still possible because the phase between the mixer signal coming from the LO and the received signal changes when the received signal changes from fm+Δf to fm–Δf. DC receivers therefore have two mixers and two "IF filters" in the so-called I and Q branches. The I and Q mixers are driven with a signal offset by 90 degrees (sine and cosine) in the process (figure 10).

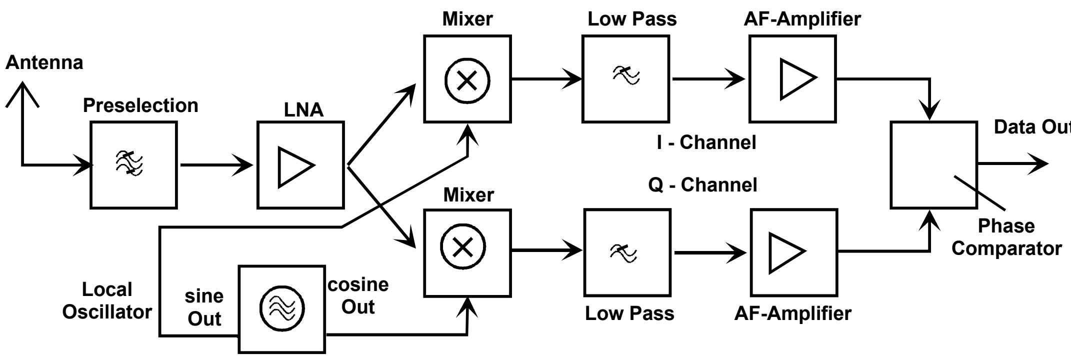


Figure 10 Circuit diagram of a direct conversion receiver

Figure 11 shows how the amplitude-time relationship changes between channels I and Q when the received signal switches from + Δf to – Δf. It is easy to see that this phase difference can be evaluated in principle.

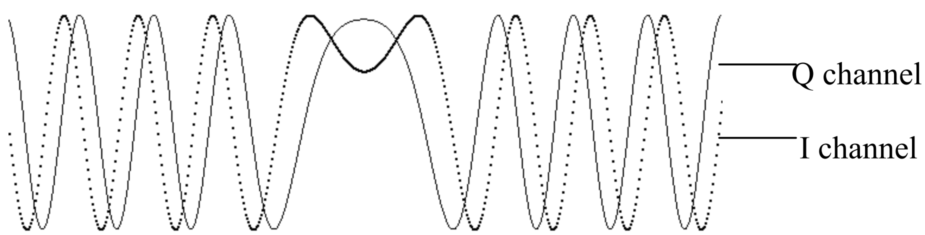


Figure 11 Amplitude-time diagram in the I and Q channel

> DC receivers produce comparatively satisfactory results at low cost although they require a broader bandwidth for the same data rate. This results in somewhat lower sensitivity.

Fast-moving objects in the vicinity of the receiver could present a problem since mixing takes place in the receiver at precisely the received frequency. Needless to say, this mixing frequency cannot be completely attenuated and is radiated backwards,

so to speak, through the aerial. If this signal meets a nearby object which is moving (ventilator) it is reflected. The resultant Doppler frequency (radar) superimposes itself on the receiving signal and causes interference.

DC receivers may react sensitively to moving objects in the vicinity.

5.2.2 Receivers with low IF

In receivers with low IF, the received signal is mixed close to the base-band or even at half the RF bandwidth. In this range of just a few tens of kHz, good active filters can simply be realised on a chip.

With a very small intermediate frequency, the image frequencies come so close to the basic channel that they can no longer be suppressed with conventional filters. Figure 12 shows a suitable process which at first glance is similar to direct conversion. In one of the two channels, the AF phase is shifted by 90^o. Both channels (I and Q) are then linked together in an addition stage. The base-band data become available following low pass filtering.

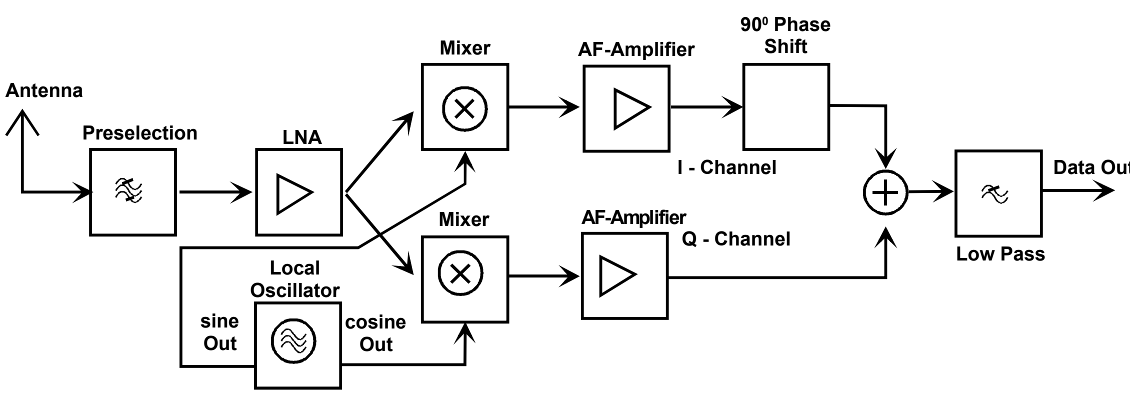


Figure 12 Circuit diagram of a receiver with low IF

Receivers with low IF make better use of the available spectrum than DC receivers.

6. Spread spectrum transmission

Originally spread spectrum transmission came from the military field. It was based on the idea of having the carrier frequency transmitted through a broad frequency range so quickly that it could no longer be detected by (conventional) enemy receivers.

If the carrier frequency does not change constantly but follows a specified digital algorithm, this is described as a “direct sequence spread spectrum” (DSSS).

When expanding the transmission band to a large spectral range, the level which can be measured by a non-synchronous receiver is reduced in proportion to the band spread (figure 13).

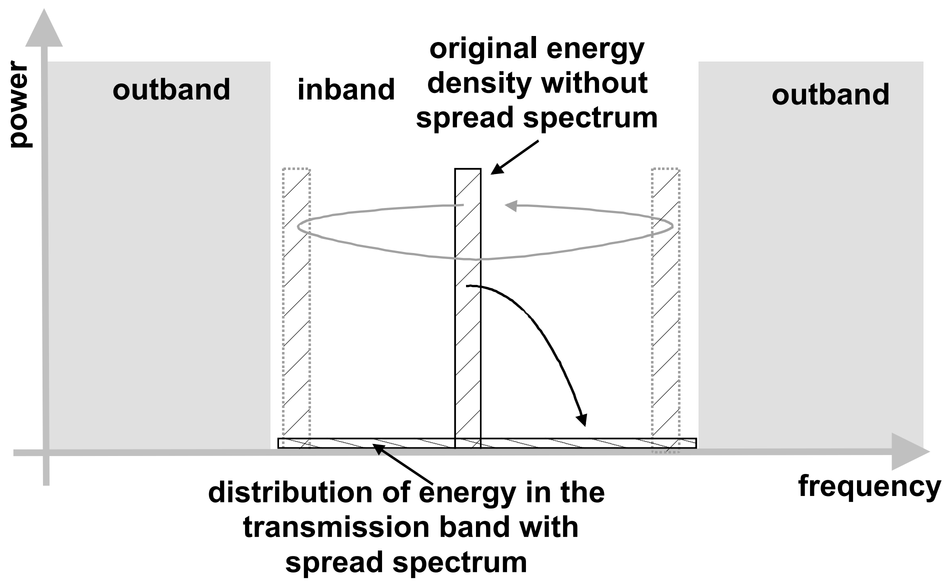


Figure 13 Energy distribution in the spread spectrum transmission channel

This factor is described as system gain G

$$G = \frac{\text{Bandwidth RF}}{\text{Bandwidth baseband}} \qquad [1]$$

It is the main parameter for spread spectrum transmission and characterises:

- the extent to which the average amplitude is reduced
- the extent to which transmission interferes with conventional receivers
- the extent to which a conventional transmission is mixed in with the spread spectrum transmission
- the extent to which spread spectrum transmissions interfere with one another

- the maximum dynamic range compared with other signals in the received band

Given the above conditions, 60 dB system gain would seem to be a reasonable minimum. At a data rate of 1 kBit/s this process would require a bandwidth of 1 GHz. At present, however, this is not realistic.

Another drawback of the system should also be mentioned. It is not easy to synchronise a receiver to a transmitter. Correlators which synchronise with a preamble are used for this.

The receiver ICs currently available still require too much energy to fit them in a fire detector. Apart from this, they only offer a comparatively modest system gain of approx. 30 dB.

At present, spread spectrum technology does not appear to be developed enough for use in fire detection systems